

ATI Ti-15Mo Beta Titanium Alloy

GENERAL

ATI Ti-15Mo beta titanium alloy (UNS R58150) is formulated from two metals with greatly different elemental densities. To ensure complete melting and to minimize molybdenum segregation, this metastable beta titanium alloy is melted in a plasma arc furnace and remelted in a VAR furnace. This binary Ti-15Mo alloy has not been successfully commercialized for chemical or aerospace industry applications, but other molybdenum containing aerospace alloys such as Ti-8Al-1Mo-1V and Ti-3Al-8V-6Cr-4Mo-4Zr are now commonly used. Ti-15Mo alloy was "rediscovered" by the medical industry because of its unique combination of properties; exceptional corrosion resistance, attractive mechanical properties, and well-documented biocompatibility¹. In the solution annealed condition, the alloy has a modulus of elasticity that is about two-thirds the modulus of Ti-6Al-4V alloy, along with considerably improved ductility and fatigue properties^{2,3}. ATI Ti-15Mo alloy is manufactured as bar, rod, sheet, and wire product forms for orthopaedic, trauma, spinal, and cardiovascular applications.

SPECIFICATIONS

- ASTM F 2066 - Bar, Rod, Sheet, and Wire

PHYSICAL PROPERTIES

Melting Range: 3,100-3,200°F (1,704-1,760°C)

Density: 0.179 lbs/cu. in.; 4.95 gm/cc

Beta Transus Temperature: 1,425 °F (± 25°); 774 °C (± 14°)

Elastic Modulus: 78 GPa in the solution annealed condition

HEAT TREATMENT

ATI Ti-15Mo alloy is usually supplied in the solution annealed and quenched condition.

1. Anneal: 1,450 - 1,800 °F (788 - 982°C), 1 hour, rapid quench to below 1,025° F (552°C).
2. Stress Relief: 1,500 °F (816 °C), 10 minutes, rapid quench to below 1,025° F (552°C).

HARDNESS

In the annealed and quenched condition, with a fully recrystallized beta phase microstructure, the strength values of ATI Ti-15Mo alloy are moderate and the ductility values are relatively high. Hardness is in the HRc 22-26 range.

FORGEABILITY/ FORMABILITY

Hot and cold workability characteristics of ATI Ti-15Mo alloy are very good, which is typical for beta titanium alloys^{4,5}. The low elastic modulus and exceptional ductility of this alloy are properties that contribute to an unusual springiness or "spring back" in forming and in machining. ATI Ti-15Mo alloy can be finish forged above the beta transus from 1,500 °F (816 °C) with a finishing temperature in the alpha plus beta region or about 1,200 °F (649 °C). An immediate water quench minimizes the formation of omega phase in thin sections of this alloy, depending upon the microstructural properties desired.

MACHINABILITY

ATI Ti-15Mo alloy can be machined with new and sharp tools using higher feed rates and reduced machining speeds. It is important to irrigate the tooling and workpiece well with large amounts of non-chlorinated cutting fluid. Alternative metal removal methods such as water jet cutting, wire EDM, and plasma cutting have been used successfully for ATI Ti-15Mo alloy components. Take special care to avoid hydrogen, oxygen, and nitrogen pick-up at exposed surfaces when performing machining, cutting, or grinding operations.

SPECIAL PRECAUTIONS

ATI Ti-15Mo alloy can be subject to hydrogen contamination during improper pickling and to oxygen, nitrogen, and carbon pickup during forging, heat treating, grinding, etc. This contamination may cause a reduction in ductility which could adversely affect notch sensitivity and forming characteristics.

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Chemistry	N	C	H	Fe	O	Mo	Ti
% w/w, min.	-	-	-	-	-	14.00	Bal
% w/w, max.	0.05	0.10	0.015	0.10	0.20	16.00	Bal

Samples for hydrogen shall be taken from the semi-finished mill product.

MECHANICAL PROPERTY DATA

	Product Form and Condition	Thickness, inches	UTS, min. ksi (MPa)	YS 0.2%, min. ksi, (MPa)	%EL, min.	%RA, min.
ASTM F 2066	Bar, Rod, and Wire; Annealed, Quenched, Cold Finished	Up to 4.00 in., diameter or thickness	100 (690)	70 (483)	20	60
ASTM F 2066	Sheet, Strip, and Plate; Annealed, Quenched, Cold Finished	Special Requirements by Agreement	105 (724)	80 (562)	12	Bend Test

Specification minimum values. Mechanical properties as a function of oxygen content have been studied. ⁶

CORROSION RESISTANCE AND BIOCOMPATIBILITY

The passive oxide film on the surface of titanium and titanium alloys is resistant to tarnish and corrosion, and also contributes to biocompatibility and osseointegratability. A tenacious mixture of metal oxides forms rapidly on the surface of any CP grade or alloy of titanium. The chemical make-up of this adherent oxide layer is a function of the chemical composition of the titanium base metal. Titanium base metal composition and the surface oxide film are important determinants of corrosion resistance, biocompatibility, and osseointegratability. Ti-15Mo alloy and CP titanium exhibit better corrosion resistance in phosphate buffered saline solutions than Ti-6Al-4V ELI and Ti-6Al-7Nb. Anodic polarization measurements show that Ti-15Mo performs better in a test corrosive environment than Ti CP-4, Ti-6Al-4V ELI, and Ti-6Al-7Nb ⁷ alloys.

NOTCH SENSITIVITY

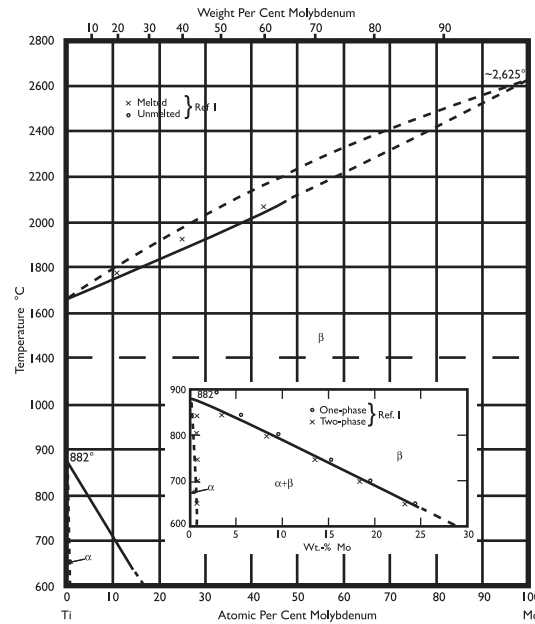
Test methods ASTM E 8 are used for tensile testing of smooth tensile specimens, and method ASTM E 602 is employed for sharp-notch tensile specimens. Ti-15Mo alloy has superior notch sensitivity resistance when compared with conventional $\alpha + \beta$ titanium alloys, Ti-6Al-4V ELI and Ti-6Al-7Nb ⁸. This is an important materials property to be considered for devices subject to scratching and for components with holes, threads, sharp edges, and in contact with other components in a implant construct.

STRESS CORROSION CRACKING (SCC) RESISTANCE

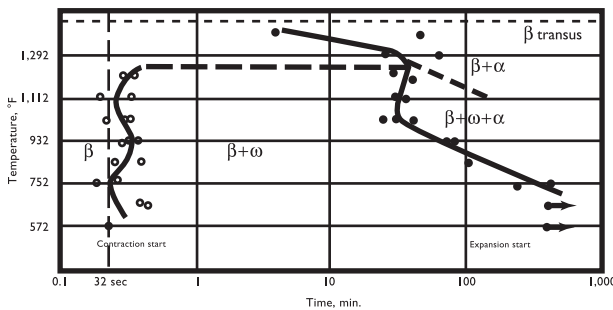
The stress corrosion cracking properties of four implantable titanium grades was investigated at the University of Mississippi Medical Center ^{9,10}. Comparable test data were generated for Ti CP-4 (ASTM F 67, α microstructure), Ti-6Al-4V ELI (ASTM F 136, $\alpha + \beta$ microstructure), Ti-6Al-7Nb (ASTM F 1295, $\alpha + \beta$ microstructure), and Ti-15Mo (ASTM F 2066, β microstructure). ATI Ti-15Mo alloy is not susceptible to SCC under the conditions tested at UMMC, nor are any of the other three titanium grades tested.

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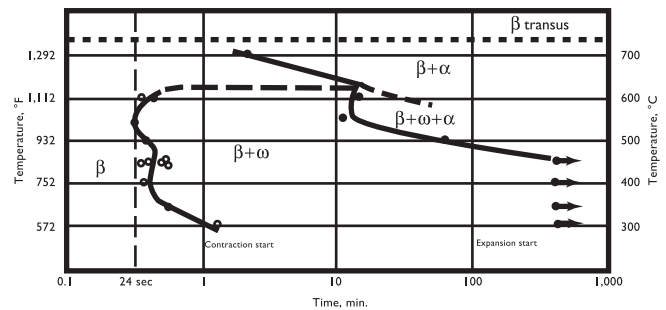
Molybdenum-Titanium Phase Diagram ¹¹



Time-Temperature-Transformation (TTT) Diagrams



TTT Diagram for Ti-12Mo Alloy ¹²



TTT Diagram for Ti-15Mo Alloy ¹³

REFERENCES

- J. Disegi, "Wrought Titanium-15Molybdenum Implant Material", Synthes (USA), Paoli PA USA (October 2003).
- IMI Titanium 205, Alloy Data Sheet, IMI Titanium Limited, Birmingham England.
- S. Steinemann et. al, "Beta-Titanium Alloy for Surgical Implants", Seventh World Conference on Titanium, San Diego CA, 28Jun-02 July 1992.
- M. J. Nutt, V. R. Jablakov, H. L. Freese, and M. E. Richelsoff, "The Application of Ti-15Mo Beta Titanium Alloy in High Strength Structural Orthopaedic Applications", ASTM International STP 1471, "Titanium, Niobium, Zirconium, and Tantalum for Medical and Surgical Applications", (December 2005), pp. 84-85.
- B. Marquardt and R. Shetty, "Beta Titanium Alloy Processed for High Strength Orthopaedic Applications", ASTM International STP 1471, "Titanium, Niobium, Zirconium, and Tantalum for Medical and Surgical Applications", (December 2005), pp. 72-76.
- N. G. D. Murray, V. R. Jablakov, H. J. Rack, and H. L. Freese, "Influence of Oxygen Content on the Mechanical Properties of Titanium-35Niobium-7Zirconium-5Tantalum Beta Titanium Alloy", ASTM International STP 1471, "Titanium, Niobium, Zirconium, and Tantalum for Medical and Surgical Applications", (December 2005), pp. 43-46.
- L. Zardiackas, D. Mitchell, and J. Disegi, "Characterization of Ti-15Mo Alloy for Orthopaedic Implant Applications", ASTM STP 1272, Medical Applications of Titanium and Its Alloys, ed. S.A. Brown and J. E. Lemons, (1966), p. 64.
- J. Disegi, "Titanium Alloys for Fracture Fixation Implants", Injury, Volume (231 Supplement 4, December 2000, p. S-d16).
- L. Zardiackas et. al, "Stress Corrosion Cracking Resistance of Titanium Implant Materials", 27th Annual Meeting of the Society for Biomaterials, St. Paul MN, 24-29 April 2001.
- R. S. Williamson, V. R. Jablakov, M. Roach, and L. D. Zardiackas, "Fatigue Of Wrought Ti-6Al-4V ELI, β -Ti-15Mo, and α/β Ti-15Mo", 9th International Fatigue Congress, Atlanta GA, (14-19 May 2006), pp. 3-6.
- M. Hansen and K. Anderko, editors, Constitution of Binary Alloys, McGraw-Hill, (1958), pp. 976-977, Molybdenum-Titanium (M. Hansen, E. L. Kamen, H. D. Kessler, and D. J. McPherson, Trans. A.I.M.E., 191 (1951), pp. 881-888).
- T. Yukawa, S. Ohtani, T. Nishimura, T. Sakai, "Phase Transformation of Titanium Alloys by Means of Automatic Transformation Apparatus," proceedings of an International Conference held at the Royal Festival Hall, London, 21-24 May, 1968, The Science, Technology and Application of Titanium, R.I. Jaffee, N.E. Promise, eds., Pergamon Press, Oxford, 1970, pp. 699-710.
- S.A. Spachner and W. Rostoker, "Transformation Kinetics of Two Titanium Alloys in the Transition Phase Region", Trans. AIME, Vol 212, December 1958, pp. 765-767.